

REVIEW

Teaching and learning natural sciences using augmented reality in preschool and primary education: A literature review

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Abstract: Augmented reality has the potential to transform and enrich Natural Sciences education. This is particularly true in preschool and primary education. This study aims to provide a literature review regarding the use of augmented reality in preschool and primary education to teach and learn Natural Sciences, Astronomy, Biology, Chemistry, Earth and Environmental sciences, and Physics. A total of 63 related studies are examined. Based on the results, augmented reality emerged as a valuable and effective educational tool that can improve teaching and learning of Natural Sciences and its branches (*e.g.*, Astronomy, Biology, Chemistry, Earth and Environmental sciences, and Physics) in kindergarten and elementary schools. Students, teachers, and parents expressed positive attitudes and emotions about the use of augmented reality in education. Students that learned through augmented reality applications achieved better learning outcomes than those who learned through traditional means and methods. Specifically, augmented reality helped students acquire a deeper understanding of the concepts taught, improved their self-learning, and increased their engagement, motivation, comprehension, flow, and academic performance. Augmented reality can also help teachers provide lessons of high quality. Moreover, the ability of augmented reality to support both formal and informal learning was evident. Augmented reality also effectively supported collaborative learning, scaffolding, and experiential learning and enabled students to communicate and interact with their peers, surrounding environment, and digital content. Finally, augmented reality arose as an educational means that can improve students' ecological empathy as well as environmental consciousness and awareness. Based on the findings, implications and future research directions are provided.

Keywords: augmented reality, natural sciences, preschool education, primary education

1 Introduction

Natural sciences involve the examination of the natural world and natural phenomena using scientific methods and consists of different disciplines, such as Astronomy, Biology, Chemistry, Earth and Environmental Sciences, and Physics (Kalogiannakis et al., 2018; Ledoux, 2002). However, natural sciences can be connected with social sciences and humanities as they also involve human-related issues (Cohen, 1994; Kagan, 2009). Natural sciences are directly connected with our understanding of the natural world. As students from a very young age start to formulate their understanding of natural phenomena and concepts, natural sciences are being integrated as part of preschool and primary education to help students lay the foundations for the development and pursuit of scientific literacy (Kastriti et al., 2022). Additionally, students' attitudes toward and perspectives of natural sciences from a young age can influence their future career interests in scientific fields (Kurniawan et al., 2019) as well as their epistemic cognition, scientific beliefs, and scientific argumentation. Nonetheless, it can be difficult for younger students to grasp and fully comprehend natural sciences due to their difficult, complex, and abstract concepts. This is particularly true when students do not have visual representations or interactive examples to complement the theoretical knowledge they acquire (Lavidas et al., 2022).

Having interactive visual representations of natural sciences concepts and laws of nature can help students improve their understanding (Zourmpakis et al., 2022). Due to their immersive nature and the educational benefits they can yield, augmented reality and virtual reality technologies are increasingly being used in educational settings to aid with teaching and learning

activities (Lampropoulos & Kinshuk, 2024; López-Belmonte et al., 2020; Rojas-Sánchez et al., 2022; Wu et al., 2013). As augmented reality enables users to remain connected and interact with their surrounding environments and due to it not requiring advanced equipment, it is becoming more widely used in preschool education (Aydoğdu, 2022; Garzón et al., 2019; Gecu-Parmaksiz & Delialioğlu, 2020; Yilmaz et al., 2017) and primary education (Alkhattabi, 2017; Hidayat et al., 2021). Through the use of computational units, augmented reality embeds digital objects and information into the real environment in a way that users can perceive them through their senses and interact with them in real time (Ampartzaki et al., 2021; Azuma, 1997; Caudell & Mizell, 1992; Lampropoulos, 2023a). Moreover, augmented reality supports different media types (Ali et al., 2017) and constructivism-based learning theories (Dunleavy & Dede, 2014). Although students' characteristics can influence learning outcomes (López-Belmonte et al., 2022), when integrated into teaching and learning activities, augmented reality can positively affect students' engagement, motivation, and learning achievements across all educational levels (Lampropoulos et al., 2022, 2023; Lin & Yu, 2023).

The aim of this study is to provide an overview regarding the use of augmented reality in preschool and primary education to teach and learn natural sciences. Emphasis is put on how augmented reality can be used in the context of Natural Sciences, Astronomy, Biology, Chemistry, Earth and Environmental Sciences, and Physics Education. The study looks into the integration of augmented reality in preschool and primary education (Section 2) and presents the method followed in Section 3. The use of augmented reality in natural sciences is examined (Section 4), and its integration into different natural sciences branches is explored. Specifically, studies that presented augmented reality applications in Astronomy education (Section 5), Biology education (Section 6), Chemistry education (Section 7), Earth and Environmental Sciences education (Section 8), and Physics education (Section 9) at the preschool or primary education level are presented and analyzed. Finally in Section 10, the findings are further discussed, implications are presented and conclusive remarks and suggestions for future research are provided.

2 Augmented reality in preschool and primary education

Preschool and primary education are an integral part of students' future success in the education system; hence, there is an increasing interest in integrating new approaches and technologies, such as augmented reality, in teaching and learning activities to support and enrich preschool and primary education (Antoniadi, 2023; Lampropoulos & Admiraal, 2023; Masmuzidin & Aziz, 2018; Stoyanova et al., 2015). Due to its immersive nature as well as its detailed and interactive digital representations, augmented reality can create interesting and enjoyable learning experiences suitable for preschool and primary education students (Albayrak & Yilmaz, 2022; Koca et al., 2019; Nincarean et al., 2019; Syahidi et al., 2019). Additionally, it can promote students' creativity and imagination (Huang et al., 2016), attract their interest and positively support peer relationships (Bilgin & Kala, 2022) which, in turn, can further amplify students' learning outcomes (Beltozar-Clemente et al., 2022; Lampropoulos, 2023b). Studies have highlighted the suitability of augmented reality to be integrated and support educational processes and the potential to further increase students' attention, knowledge acquisition, comprehension, and motivation when compared to using only traditional methods of learning (Aydoğdu, 2022; Gecu-Parmaksiz & Delialioğlu, 2019).

However, it is important to apply appropriate design methods (Rohaya et al., 2012), development approaches (Abrar et al., 2019), and usability principles (Tuli & Mantri, 2020) when creating augmented reality educational resources. Well-designed augmented reality interventions can positively affect students' cognitive mechanisms, increase their focus on the learning activities, encourage them to reflect and revise the learning material, and provide them with opportunities to apply what they learn (Campos-Pajuelo et al., 2022; Iquirá-Becerra et al., 2020; Oranç & Küntay, 2019). When augmented reality applications are integrated into preschool and primary education, increased interaction and engagement with the material which, in turn, results in improved academic performance can be observed, even if students are not initially familiar with the technology (Abrar et al., 2019; Campos-Pajuelo et al., 2022; Safar et al., 2016; Stoyanova et al., 2015).

Studies have also reported that when adopting augmented reality to present natural sciences educational contents, students' learning outcomes and learning motivation improved more than when using traditional methods of teaching (Cascales et al., 2012, 2013; Lu et al., 2020).

Additionally, augmented reality can positively affect the educational process and increase students' focus and engagement and constitutes an effective educational tool that can support teachers to provide lessons of higher quality (Ozdamli & Karagozlu, 2018). Despite the potential benefits that the integration of augmented reality can have in preschool and primary education in the teaching of natural sciences, there is a clear need for training and development programs for teachers to become more familiar with augmented reality, improve their digital skills, and learn how to effectively introduce it to their classrooms (Jančaříková & Severini, 2019; Safar et al., 2016; Stoyanova et al., 2015).

Therefore, augmented reality applications can support preschool and primary education while enhancing students' social skills, performance, and motivation, providing interactive and fun learning experiences, and helping them develop positive attitudes toward science (Ewais & Troyer, 2019; Kamarainen et al., 2013; Masmuzidin & Aziz, 2018; Patricio et al., 2019). Additionally, both teachers and parents showcase a positive attitude regarding augmented reality didactic resources in preschool and primary education as they can offer adaptive learning experiences and support that their students present increased learning motivation and comprehension when using augmented reality material which, in turn, leads to more effective learning (Abrar et al., 2019; Cascales et al., 2013; Huang et al., 2016; Utami et al., 2020).

3 Methods

As the aim of this study is to explore the role and impact of augmented reality on natural sciences education in preschool and primary education, a critical literature review or integrative literature review approach was adopted. Specifically, as the main branches of natural sciences were examined in both educational levels, the critical literature review approach was selected as the most suitable approach since a creative collection of data was required (Snyder, 2019). Following the guidelines presented in (Jesson & Lacey, 2006), a thorough search for suitable scientific articles in established databases, repositories, and indexes (*e.g.*, ACM, Google Scholar, IEEE, Scopus, Web of Science, *etc.*) was conducted using different keywords for each educational level and scientific branch. The inclusion criteria for a study to be considered were for it to: i) involve preschool or primary education students, ii) examine and/or present an augmented reality intervention, and iii) focus on natural sciences and/or one of its scientific branches. A total of 63 related studies were identified, assessed as suitable, and examined in the context of this study.

4 Augmented reality in natural sciences education

Several empirical studies have explored the adoption and integration of augmented reality as a means to support and enrich natural sciences in preschool and primary education. Cascales et al. carried out two studies (Cascales et al., 2012, 2013) in which they examined the feasibility of integrating augmented reality in preschool education to support learning of natural sciences. A total of 36 preschoolers (experimental group: 18 students and control group: 18 students) took part in their experimental study. Based on the outcomes of both studies, the preschoolers found the application interesting and were able to effectively use it. Improvements on students' learning outcomes were also observed for students of the experimental group in comparison to those of the control group. Augmented reality emerged as an effective tool to teach natural sciences to preschoolers. Looking into how augmented reality inquiry activities can improve students' learning motivation and achievements in the context of natural science learning, Chiang et al. (2014) carried out an experimental study involving 57 primary education students (experimental group: 28 students and control group: 29 students). Based on the results, the students of the experimental group showcased significantly higher levels of attention, confidence, and motivation than those of the control group. Additionally, students who learned using the augmented reality application achieved better learning achievements. However, no significant difference was observed regarding students' cognitive load. Stoyanova et al. (2015) explored the use of augmented reality to support primary education students' learning of natural sciences. Primary education students from different schools took part in the study. Students positively assessed the augmented reality application which triggered their interest and curiosity. Teachers also had a positive attitude toward its use to help teaching natural sciences concepts. In addition, learning through the use of the augmented reality application emerged as interesting and enjoyable. Not requiring students' preliminary training on how to use the application as it felt natural to them arose as a benefit of adopting augmented reality in education.

Moreover, Fakhruddin et al. carried out two studies (Fakhruddin, 2018; Fakhruddin et al., 2017)

examining the use of an augmented reality application in primary education in the context of natural sciences. Initially, the suitability of the application was evaluated by 10 students and 2 teachers. After being further improved, the application was integrated into classrooms and assessed by 2 teachers and 25 students. The application was positively evaluated by both students and teachers who regarded it as an efficient learning means to teach natural sciences in primary education. The augmented reality application increased students' learning outcomes in terms of affective and psychomotor aspects. Focusing on supporting primary education students' learning of natural sciences concepts through augmented reality virtual representations, [Hendajani et al. \(2018\)](#) presented a markerless augmented reality application. The potential of augmented reality to display detailed representations of natural sciences concepts was highlighted. To aid teaching and learning natural sciences in primary education, [Midak et al. \(2019\)](#) focused on presenting an interactive augmented reality application. The potential of augmented reality to support natural sciences and their scientific branches was highlighted. Providing interactive 2D and 3D representations emerged as a main benefit of augmented reality. Additionally, its ability to create opportunities for experiential learning in secure environments which can improve students' comprehension and recall of the concepts taught as well as increasing their engagement, motivation, and critical thinking was highly regarded. [Istiningsih et al. \(2020\)](#) examined the use of augmented reality as a learning medium to support teaching and learning of natural sciences. In total, 10 primary education students participated in the study and assessments by 3 experts and a teacher were also analyzed. Based on the experts' feedback, the augmented reality application was suitable for primary education students and effective in teaching natural sciences concepts. The teachers also had a positive attitude toward the integration of augmented reality in classroom activities. Students also expressed positive attitudes and their comprehension of the subjects taught increased.

Furthermore, [Anggara et al. \(2021\)](#) looked into the use of augmented reality and virtual reality to support teaching and learning of natural sciences in primary education. A total of 5 students took part in the study which followed an experimental design. Students who used the applications acquired a better understanding of the concepts taught and performed better. Focusing on improving the quality of natural science learning in primary education, [Atmojo et al. \(2021\)](#) looked into the adoption and integration of augmented reality in teaching and learning activities. The study involved 120 students (experimental group: 60 students and control group: 60 students). Students of the experimental group demonstrated better academic performance. Augmented reality emerged as an efficient educational tool that can help teachers and effectively support students' learning of natural sciences. [Rukayah et al. \(2021\)](#) focused on examining augmented reality as a means to create effective natural science learning media. Primary education teachers and 116 primary education students participated in the study which followed a mixed method approach. Based on the outcomes, teachers highly regarded the use of augmented reality and assessed that it can effectively complement natural sciences learning. However, teachers were not familiar with the existence of such tools and stated that there is a need for more widely used augmented reality educational resources to be created. Students had a positive attitude toward the augmented reality experience which triggered their interest. Additionally, they highly regarded the use of interactive audiovisual information. The need to develop more augmented reality multimedia targeted at natural sciences learning was highlighted. Aiming at supporting natural sciences learning in primary education, [Salvador-Herranz et al. \(2011\)](#) explored the use of augmented reality and its effect on students' learning satisfaction and performance. A total of 12 primary education students took part in their study. According to the outcomes, students found the application useful and enjoyable and their academic achievements and learning satisfaction increased. The ability of augmented reality to effectively enrich natural sciences and their branches emerged. In a study involving 109 primary education students (experimental group: 57 students and control group: 52 students), [Huang et al. \(2022\)](#) explored the use of augmented reality as a means to support natural science courses. The outcomes of the study indicated that students that learned through the use of the augmented reality application demonstrated a more positive attitude toward natural sciences and achieved better academic performance. The ability of augmented reality to provide interactive and detailed visual representations was highly regarded. No differences were found in terms of students' gender. It was highlighted that the integration of augmented reality in education can enhance blended learning and create new teaching and learning opportunities.

5 Augmented reality in astronomy education

In order for younger students to acquire a better understanding of astronomy concepts, having detailed virtual representations could facilitate their learning and comprehension. Studies

have focused on examining how augmented reality can be used in preschool and primary education to aid with learning of astronomy concepts. Specifically, [Fleck & Simon \(2013\)](#) explored how augmented reality 3D models can influence primary education students' learning of Astronomy concepts and phenomena in comparison to the physical models. Their study adopted an experimental design approach and 39 primary education students (experimental group: 20 students and control group: 19 students) participated. Based on their findings, learning was more effective and meaningful when supported by augmented reality as it enabled students to develop scientific conceptions and a better understanding of the astronomical phenomena. It was also highlighted that augmented reality can increase task controllability, offer collaborative learning experiences, support scaffolding, and increase learning motivation. [Zhang et al. \(2014\)](#) looked into how augmented reality can support teaching and learning of astronomical concepts. Their study adopted a quasi-experimental design and involved 200 primary education students. The augmented reality application positively affected students and improved their astronomical knowledge and observation skills. Additionally, students who used the augmented reality application demonstrated higher levels of learning interest and knowledge retention. The ability of augmented reality to support and enrich both formal and informal learning was highlighted. Focusing on the effect of using augmented reality to support astronomy concepts learning, [Arcos et al. \(2016\)](#) carried out a study involving 63 primary education students. Following a quantitative analysis, their findings revealed that students who learnt using the augmented reality application achieved better grades than those using traditional methods. The potential of augmented reality to improve students' comprehension and stimulate their cognitive development was also highlighted.

Furthermore, [Lisboa et al. \(2019\)](#) examined how augmented reality can support preschoolers' astronomy concepts learning through a quasi-experimental study. A total of 53 preschool students participated in their study. Through the realistic representations of astronomical phenomena and events, augmented reality emerged as a tool that enabled students to acquire a better comprehension of the concepts being taught. In addition, students were able to communicate their ideas and interact with other students. Augmented reality arose as an effective learning tool that can enrich astronomy concept learning in preschool education by providing interactive educational resources and rendering the educational experience more enjoyable and engaging. [Patricio et al. \(2019\)](#) presented an augmented reality application which was developed with the aim of supporting Astronomy education in primary education. The augmented reality application and learning experience were evaluated by 70 students. The majority of the students had a positive attitude toward the augmented reality application and stated that through its use, more enjoyable and interactive learning experiences can be created. Teachers also positively assessed the intervention and were favorable toward its benefits to students. The ability of augmented reality to provide students with more realistic experiences regarding astronomy concepts was highly regarded. [Midak et al. \(2020\)](#) focused on the development of an augmented reality application targeted at supporting astronomical concepts learning in primary education. The potential of augmented reality to visualize concepts and phenomena in an interactive manner and improve students' spatial thinking was highlighted. The ability of augmented reality to increase students' knowledge acquisition by providing them with hands-on experiences was emphasized.

Moreover, [Zuniari et al. \(2022\)](#) looked into how augmented reality can support knowledge acquisition and critical thinking in the context of a solar system course in primary education. Their study followed a quasi-experimental design and a total of 56 primary education students (experimental group: 28 students and control group: 28 students) participated. Based on the outcomes, a significant difference in terms of academic performance was observed. Specifically, students who learned through the use of the augmented reality application performed better and acquired a better understanding of the concepts taught. The study of [Düzyol et al. \(2022\)](#) involved the examination of how augmented reality applications can influence preschool students' knowledge of space. Their study followed an experimental design approach and both qualitative and quantitative methods were used to analyze the data. A total of 24 preschoolers participated in the study. Based on the outcomes, although students of the experimental and control groups had initially similar levels of knowledge regarding space, after training, students of the experimental group showed an increase in their level of knowledge. Moreover, the results of the interview with students revealed that students positively assessed the augmented reality learning experience as it provided them with a more realistic experience, increased their enthusiasm, and drew their attention more. [Chen et al. \(2022\)](#) examined the creation of situated learning through the development of an augmented reality application to teach Astronomy to primary education students. In total, 80 primary education students (experimental group: 40 students and control group: 40 students) took part in their study which adopted a quasi-experimental approach and

used a qualitative analysis. Their results revealed that students who used the augmented reality application showcased higher levels of flow and learning motivation and achieved better learning outcomes. Students' learning engagement and enthusiasm emerged as two key elements in the realization of effective learning which augmented reality intervention can also increase.

6 Augmented reality in biology education

Studies have also examined how augmented reality can be integrated into Biology courses and curricula and how it can affect students' learning outcomes. [Nainggolan et al. \(2018\)](#) developed an augmented reality application targeted at preschool students. Specifically, their study focused on identifying methods and specifications to provide better visual representations of information through the use of augmented reality. It was highlighted that due to its interactive nature, augmented reality can help teachers introduce new concepts and their characteristics to students of young age. [Nuanmeesri \(2018\)](#) examined how augmented reality intervention can influence students' knowledge acquisition and understanding of the concepts taught. A total of 30 primary school students took part in the study which followed a quasi-experimental design. The outcomes revealed that augmented reality is positively assessed as an effective educational tool to teach biology concepts to primary education students. Additionally, the use of augmented reality provided students with a better representation of the concepts taught which, in turn, resulted in them achieving better performance and a deeper understanding of the concepts. Focusing on the role of augmented reality in preschool education, [Abrar et al. \(2019\)](#) explored the effectiveness of an augmented reality application. Their study followed a quasi-experimental design and involved 41 participants (25 students, 13 parents, and 3 teachers). Their results highlighted that through the integration of augmented reality, students' knowledge acquisition and recall increased and they acquired a better understanding of the concepts being taught. Additionally, augmented reality emerged as an effective and useful teaching tool in preschool education which can enrich traditional learning and improve students' motivation and engagement. [Koca et al. \(2019\)](#) explored the use of augmented reality applications for preschool students. Focusing on creating more enjoyable learning experiences, an augmented reality application was developed and integrated within preschool classrooms. The results revealed that in addition to improving learning outcomes, augmented reality can also render the learning experience more fun for students which, in turn, can improve their engagement and motivation.

Furthermore, [Iqira-Becerra et al. \(2020\)](#) looked into usability considerations of introducing augmented reality in classrooms and compared different learning methods. Their study involved 45 preschool students who were randomly divided into three groups with each one using different teaching methods (*e.g.*, traditional learning with physical objects, augmented reality self-learning, and augmented reality guided learning). In both cases in which augmented reality was used, students who learned through augmented reality outperformed those that used only traditional teaching methods and materials. Guided learning yielded better learning outcomes than self-learning. Therefore, it can be inferred that although augmented reality can positively influence learning outcomes, the role of teachers remains crucial. The need to select appropriate for each case augmented reality techniques and design approaches was also highlighted. Additional emphasis should be put on clarity, simplicity, and usability when the target group is young students. Focusing on exploring how augmented reality can influence students' motivation and performance in natural science subjects, [Lu et al. \(2020\)](#) conducted a study in which 53 primary education students participated. The results of their quasi-experimental study highlighted that augmented reality can effectively support the educational process. Specifically, students that learned through the use of the augmented reality application achieved higher learning outcomes. However, a relative drop in student confidence was observed and no significant differences were found in terms of students' learning motivation. Following a quasi-experimental design, [Cruzado et al. \(2020\)](#) examined the impact of augmented reality on students' learning outcomes and knowledge acquisition. A total of 62 preschool students participated in their study. Better learning outcomes in terms of classification and recognition were observed. Additionally, students who used the augmented reality application showcased increased levels of satisfaction, comprehension, and motivation. It is also worth noting that a significant difference in the duration to perform the specific tasks was observed as students who used the augmented reality application managed to complete them faster while also attaining better results. Focusing on augmented reality-based flashcard media, [Utami et al. \(2020\)](#) explored the integration of augmented reality in preschool classrooms. Following a qualitative approach, their results revealed that augmented reality through its realistic and interactive virtual representations can enrich the educational process as it enables students to acquire a better understanding of the concepts being taught. When combined with flashcards media, augmented reality can result

in learning experiences which attract students' interest, enthusiasm, and attention. Its role as an effective teaching means that can be used by both teachers and parents to support students' learning was highlighted.

Moreover, [Aydoğdu \(2022\)](#) focused on how augmented reality interventions can affect preschoolers' conceptual skills, attention, and motivation. Their study followed an experimental design and involved 26 preschool students (experimental group: 13 students and control group: 13 students). Their findings indicated that augmented reality can effectively be applied in teaching and learning activities in preschool education. Specifically, students in the experimental group showcased increased levels of attention, conceptual skills, and motivation when compared to students in the control group who used traditional methods of learning. [Fadhli et al. \(2022\)](#) explored the role and impact of augmented reality in the context of a biology curriculum. In total 132 preschool students and 43 preschool teachers took part in the study. The outcomes of the study highlighted the role of augmented reality as an efficient means to teach biology related curriculum. In addition, it can increase students' attention and positively affect their learning achievements. The flexibility of augmented reality applications to display information without requiring physical resources emerged as a significant benefit. Due to its playful nature, augmented reality can increase students' engagement and provides them with opportunities to be involved in collaborative learning. [Abdullah et al. \(2022\)](#) investigated the effect of augmented reality on students' learning outcomes in science education. Their quasi-experimental study involved 60 primary education students. The effectiveness of augmented reality was highlighted as students of the experimental group showcased increased satisfaction, knowledge acquisition, and interest. Additionally, learnability and self-learning also improved when using augmented reality. Nonetheless, no significant differences were observed regarding students' attitudes. In a recent study, [Yılmaz & Gözümlü \(2023\)](#) examined preschool students' knowledge acquisition when using augmented reality applications. Their study adopted an experimental design approach and involved 37 preschool students (experimental group: 18 students and control group: 19 students) and two preschool teachers. Based on the outcomes, students in the experimental group attained a better and more detailed understanding of the subject and achieved better learning outcomes overall. Students' ability to interact with the virtual representations and thoroughly examine them emerged as a significant factor which led to improved learning performance.

7 Augmented reality in Chemistry education

Chemistry education is characterized by abstract and complex concepts which may be difficult for young students to comprehend. However, through its realistic and interactive virtual representations, augmented reality can support teaching and learning of Chemistry. Studies have been conducted to examine how the integration of augmented reality can influence students' learning in both preschool and primary education.

[Boletsis & McCallum \(2013\)](#) presented their augmented reality application which aimed at supporting Chemistry teaching and learning in primary education. The potential of augmented reality to offer exciting and engaging learning experiences was highlighted. Involving students during the design and development process emerged as a determining factor in the creation of effective educational interventions. Aiming at supporting Chemistry education, [Chang & Chung \(2018\)](#) examined how the integration of augmented reality can influence students' learning. Their study followed a quasi-experimental design and 55 primary education students (experimental group: 28 students and control group: 27 students) participated. Based on their findings, augmented reality can be used by teachers as a supportive to the learning process tool which was favorably assessed by students who expressed a positive attitude towards its integration in the classroom. Moreover, students' knowledge and grades improved when studying through the augmented reality application and their learning motivation was increased. The interactive nature of augmented reality was highly regarded. [Nurpandi & Gumelar \(2018\)](#) and [Jin et al. \(2019\)](#) presented their augmented reality applications which aimed at supporting Chemistry learning in primary education. The ability of augmented reality to provide detailed, realistic, and high-quality representations of Chemistry concepts while also allowing students to interact with them emerged as the main benefit of such applications. Additionally, the minimization of resources required to conduct experiments so that students get a better understanding of the concepts taught also arose a significant benefit. [Ewais & Troyer \(2019\)](#) focused on examining the attitude of students regarding the adoption of augmented reality interventions in Chemistry education. In total, 50 primary education students took part in the study. According to their findings, students deemed that the augmented reality application could help them improve their

knowledge and they had a positive attitude toward its use in the learning process. The ability of augmented reality to allow students to more actively interact with the learning material which, in turn, can potentially improve their learning outcomes was highlighted.

[Alam et al. \(2020\)](#) examined how augmented reality can support teaching Chemistry in primary education. Their study revealed that augmented reality can facilitate the understanding of abstract and difficult concepts and enables students to learn in an engaging and entertaining way. Additionally, the potential to create interactive and collaborative learning environments was pointed out. Focusing on supporting abstract concepts learning in the context of chemistry education, [Olim & Nisi \(2020\)](#) conducted a study in primary education. Specifically, their study followed a mixed method approach and 36 primary education students took part. Based on their results, increased learning outcomes were observed when students used the augmented reality application. The ability of augmented reality to support situated and constructive methods was highlighted and it emerged as an effective tool that can be applied in both formal and informal learning environments. [Campos-Pajuelo et al. \(2022\)](#) looked into the integration of augmented reality in primary education and examined design and usability considerations. Focusing on Chemistry education, their application arose as user-friendly and easy to use by participants. [Olim et al. \(2023\)](#) explored how augmented reality can support the teaching and learning of chemistry concepts. Their quasi-experimental study involved 30 primary education students and adopted a mixed method approach. Based on their findings, students, who learned using the augmented reality application, showcased increased learning engagement and achieved better learning outcomes than those who used only traditional methods. The interactive and tangible interfaces of augmented reality and the descriptive representations it can offer were pointed out.

8 Augmented reality in earth and environmental sciences education

Text It is particularly important to teach earth and environmental sciences related concepts to students from a young age so that they become aware of their surroundings and cultivate environmental consciousness. Studies have examined how the use of augmented reality can affect students' learning of such concepts. More specifically, [Kamarainen et al. \(2013\)](#) looked into the use of augmented reality as a means to support environmental education field trips. Three teachers and 71 primary education students took part in their study which used observations and interviews. Through their qualitative analysis, augmented reality emerged as an effective educational tool. Specifically, students' comprehension and affective measures improved when using the augmented reality application. Additionally, teachers also deemed the use of the application as effective since it promoted student-centered learning and allowed students to interact with their classmates and their surrounding environment. Augmented reality also created new ways for students to interact and explore the environment which, in turn, led to them achieving a deeper understanding of the environmental principles. Both teachers and students had a positive attitude toward the use of augmented reality in primary education and believed that its adoption and integration in educational activities can yield several benefits. Focusing on marine education in the context of environmental education, [Lu & Liu \(2015\)](#) analyzed the use of an augmented reality application in primary education. In their study, 51 primary education students participated. Based on their findings, the use of augmented reality helped students get a better understanding of the concepts taught and improve their knowledge acquisition. It is worth noting that the highest increase in academic performance was observed among low academic achievers. Students positively viewed the use of the application and characterized the educational experience as satisfactory.

In a study involving 241 primary education students, [Theodorou et al. \(2018\)](#) looked into the influence of an augmented reality application in the context of environmental education. Their findings revealed that students of different primary education grades were favorable to the integration of augmented reality and had a positive attitude toward its use. Additionally, students' learning experience and cognitive performance improved. Augmented reality emerged as an effective tool to support teaching and learning of environmental concepts. [Koutromanos et al. \(2018\)](#) evaluated an augmented reality application for environmental education. Their study involved primary education and a total of 40 students took part. Students expressed a positive attitude toward the augmented reality application and its use in their learning experience and found it useful, enjoyable, and easy to use. The need to apply appropriate design approaches to ensure high readability of augmented reality content and information was highlighted. [Pressick-Kilborn et al. \(2018\)](#) explored the promotion of environmental education through the use digital technologies in primary education. Through the examination of different

educational applications, augmented reality emerged as a promising educational means that can support environmental education in both formal and informal learning environments. Its high interactivity and connectivity with the real environment were highly regarded.

To support environmental studies, [Wickramapala et al. \(2019\)](#) explored the impact of augmented reality and how it can support primary education. A total of 100 primary education students participated in the study which followed a quasi-experiment design. Their results showcased that augmented reality helped students attain a deeper understanding of the concepts taught. Additionally, the application allowed students to be engaged in self-learning which, in turn, increased their learning outcomes. The potential of augmented reality to provide students with additional online-based educational resources was also highlighted. In the context of environmental education, [Chien et al. \(2019\)](#) investigated the use of augmented reality to aid students' botanical learning. In total, 54 primary education students took part in their experimental study. According to the results, students that used the augmented reality application achieved a more in-depth comprehension of the concepts being taught than those of the control group. Augmented reality emerged as an effective approach to teach environmental related concepts as it has the potential to significantly improve students' higher-level cognitive capabilities. Additionally, the ability of augmented reality to create engaging experiential learning environments in the context of science education was highlighted. [Ng et al. \(2020\)](#) explored how students' learning of natural environment can be enhanced using augmented reality. Their study focused on primary education and a total of 50 students were involved. The results of their study highlighted that augmented reality can effectively support and improve learning of the natural environment. In particular, students positively evaluated the application, had a positive attitude toward its integration in learning activities, and reckoned it as a meaningful learning tool to explore and learn about the natural environment. The ability of augmented reality to simulate past and future states of environments as well as to provide additional information about their surrounding environment and objects were highly regarded. [Lee & Yoon \(2020\)](#) examined the role of augmented reality as a means to promote environmental sustainability. Their experimental study focused on primary education and 30 students (experimental group: 16 students and control group: 14 students) were involved. Based on the results, augmented reality positively influenced students' learning and environmental attitudes. A significant difference was observed in the increase of environmental consciousness with students of the experimental group showcasing more increased environmental awareness and attitudes than those of the control group. Additionally, the impact was larger on younger students. It can be inferred that it is important to enrich environmental education and instill environmental awareness into students from a young age. Hence, augmented reality arose as an effective tool that can positively affect students' perceptions of and empathy toward the environment.

[Chen \(2022\)](#) examined the influence of augmented reality in environmental education. Their study focused on primary education students. In total, 52 students from different cultures were involved. Based on their findings, students' science learning self-efficacy was positively correlated with their environmental attitude which in turn was positively correlated with their environmental behavior. Additionally, although augmented reality did not directly influence students' environmental behaviors, it positively affected their environmental attitudes through visual representations. The need to include more interactive educational material as well as clear explanations and guidelines when displaying information through augmented reality was highlighted. Aiming at enhancing student environmental awareness, [Safitri et al. \(2022\)](#) carried out a study examining the use of augmented reality in the context of environmental education. Their study followed an experimental design and a total of 286 students (experimental group: 143 students and control group: 143 students) took part. A significant difference was observed in terms of students' environmental awareness as the average value of students of the experimental group was significantly higher than that of the control group. Therefore, it can be inferred that augmented reality can effectively support environmental education and improve students' environmental awareness. In the context of environmental education, [Wei & Lu \(2023\)](#) examined the use of augmented reality in marine education. Specifically, their study adopted an experimental design focused on preschool education and a total of 60 preschoolers (experimental group: 30 students and control group: 30 students) took part. Students of the experimental group showcased increased learning achievement, motivation, attention, satisfaction, relevance, and confidence than those of the control group. It is worth noting that the students had a high level of technology acceptance and assessed the use of augmented reality positively. Therefore, it can be inferred that augmented reality can be used as an effective educational tool to teach environmental science concepts to preschool students. Focusing on improving primary education students' environmental awareness, [Ozturk & Akcay \(2023\)](#) carried out a study examining the use of augmented reality as an educational means.

A total of 17 primary education students participated in the study which used semi-structured interviews. Overall, students expressed positive emotions and attitudes toward the use of augmented reality. Additionally, its use in educational activities facilitated students' learning and increased their curiosity and intrinsic motivation. Due to its close relationship with the real environment, augmented reality improved students' environmental knowledge and behaviors increasing, thus, their environmental awareness and consciousness. [Wen et al. \(2023\)](#) examined the integration of augmented reality into inquiry-based learning in the context of science learning in primary education. In total, 117 primary education students (experimental group: 77 students and control group: 40 students) participated in the study which followed a mixed method approach. According to their findings, although no significant differences were observed in relation to students' academic performance, students' knowledge creation efficacy skills, self-directed learning, and critical thinking were significantly increased when learning through the augmented reality application. The potential of augmented reality to improve the academic performance of students who are academically weaker in science was highlighted.

9 Augmented reality in Physics education

As more advanced Physics concepts are mostly taught in higher educational levels, most studies have looked into how augmented reality can be used in Physics education in the context of secondary and higher education. Nonetheless, there are some studies that have examined the role and impact of augmented reality to teach students of younger ages Physics concepts. Focusing on exploring the use of augmented reality to improve Physics learning, [Enyedy et al. \(2011\)](#) conducted a study regarding Physics education in primary education. A total of 43 primary education students were involved in the study which followed an experimental design. Augmented reality emerged as an effective tool to teach students Physics concepts as it enabled them to acquire a deeper understanding of the concepts taught. The ability of augmented reality to support embodied learning was highlighted. It is worth noting that augmented reality allowed students of younger ages to learn about and understand concepts that were meant for older students. In a follow-up study, [Enyedy et al. \(2012\)](#) further confirmed and expanded upon these outcomes highlighting the role of augmented reality in primary education to effectively teach students Physics concepts and promote self-learning.

[Ibanez et al. \(2015\)](#) examined how augmented reality-based simulators can be used to support Physics concepts learning. A total of 40 students took part in their study. The results of the study indicated that augmented reality can effectively support Physics education. However, the need to take into account the integration of scaffolding options to further improve the learning effectiveness of augmented reality was highlighted. This is particularly true for students who have lower levels of learning motivation or self-regulation skills. Focusing on examining how augmented reality can enrich and support Physics education, [Tsiavos & Sofos \(2019\)](#) conducted an experimental study involving 44 primary education students (experimental group: 22 students and control group: 22 students). According to their findings, augmented reality emerged as an effective tool that can drastically change teaching and learning processes and result in better learning outcomes. Students' interest and attitude toward Physics lessons improved. Additionally, students that learned using the augmented reality application achieved better academic performance than those who studied through traditional methods of learning. [Wahyu et al. \(2020\)](#) carried out a study involving the use of augmented reality to improve scientific literacy in primary education. The data of 175 students (experimental group: 87 students and control group: 88 students) was examined. Based on the results, a significant increase in students' science literacy and academic achievements was observed. Specifically, students of the experimental group achieved higher levels of science literacy and showcased increased learning outcomes in comparison to those of the control group.

10 Discussion and conclusions

Natural sciences are directly connected with the way students perceive the natural world. Hence, when students study and explore natural sciences from a young age, they acquire a better understanding of natural phenomena and concepts. The effective natural sciences education can affect students' scientific beliefs, scientific argumentation, and epistemic cognition as well as their interest in pursuing a career in scientific fields. Despite the benefits associated with studying natural sciences, there are abstract and complex concepts, principles, and natural laws that are difficult to fully comprehend without having visual representations. This is particularly true in the case of younger students in preschool and primary education. Extended reality technologies can yield several benefits to the educational process. Specifically, augmented reality has proven

to be an effective tool that can support the educational process by embedding interactive virtual representation of digital content and information in users' physical environment. Due to its nature, augmented reality has the potential to enrich natural sciences education.

This study aimed at providing a critical review of the existing literature focusing on empirical studies that delved into the use of augmented reality to teach and learn Natural Sciences, Astronomy, Biology, Chemistry, Earth and Environmental sciences, and Physics in preschool and primary education. The outcomes that derived from the studies that focused on Natural Sciences education are in line with those of the studies that put emphasis on the branches of natural sciences.

Specifically, based on the results of the studies examined, augmented reality emerged as a useful, effective, and suitable educational means to support and enrich teaching and learning of natural sciences. Students, teachers, and parents expressed positive attitudes and emotions regarding the adoption of augmented reality in Natural Sciences education. All of the studies analyzed reported that students who learned through augmented reality applications achieved positive and increased learning outcomes when compared to those that used traditional methods of teaching. In particular, when using augmented reality applications, students demonstrated increased levels of motivation, engagement, flow, and comprehension. Additionally, they showed increased focus, curiosity, and interest in the learning process and material. The academic performance of students that learned through augmented reality was either higher or significantly higher than the performance of those who studied using traditional means and methods. Augmented reality also created enjoyable and entertaining learning experiences and helped students acquire a deeper understanding of the concepts taught.

Besides the benefits that the integration of augmented reality in preschool and primary education can yield for students, augmented reality also arose as a tool that can support and help teachers provide high-quality lessons. Augmented reality not requiring specialized and expensive equipment and devices to be used was considered as another benefit by teachers. However, the need for teacher training and development programs on how to use augmented reality and other digital technologies emerged. Additionally, the need to develop more openly accessible augmented reality educational resources was evident.

However, to develop and integrate effective augmented reality interventions, emphasis should be put on the selection and use of appropriate design and pedagogical approaches and methods (Fisch, 2013). It is also important to involve students and other education stakeholders when designing and developing augmented reality applications. When augmented reality is integrated in a student-centered manner, it can effectively support and improve both formal and informal learning. Additionally, it can provide opportunities for collaborative learning and allows students to communicate and interact with their peers, surrounding environment, and digital content. Through its immersive and secure environments as well as through the detailed and interactive virtual representations that augmented reality offers, it promotes and supports experiential learning, scaffolding, and self-learning. Another benefit that was noticed was students' increased ecological empathy as well as environmental consciousness and awareness.

Nonetheless, when comparing the current state of the art and the number of studies that have explored the use of augmented reality in natural sciences, it becomes evident that more studies focus on secondary and higher education. Therefore, there is a need for more empirical studies to be carried out in primary education and specifically in preschool education where there is a lack of relevant studies. Future studies should also examine how students' characteristics might influence the augmented reality intervention.

Conflicts of interest

The author declares that there is no conflict of interest.

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